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Rhythmic igneous layering from the Gilgarna Rock syenite, Yilgarn Block, Western Australia

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Abstract

A rare example of rhythmic igneous layering from the felsic alkaline suite of the eastern Yilgarn Block occurs at Gilgarna Rock. Features of the layering, and the general petrographic character of the rocks, are consistent with production of the layering via the influence of an exsolved aqueous fluid. Depletion of fluorine within the melt is believed to have facilitated production of the aqueous fluid. Cyclic variations in fluid pressure are thought to have resulted in alternating pyroxene-feldspar crystallization, leading to the development of the rhythmic layering. Development of sedimentary-type structures indicates minor modification of the original layering, possibly via the current action of fluid movement during pressure release.

Introduction

Rhythmic igneous layering is characterized by pronounced systematic repetition of distinctive layers or sequences of layers, on scales varying from centimetres to metres. Rhythmic layering has been attributed to a number of processes, including crystal settling, convection and density grading (Wager & Brown 1968); liesegang-type growth (McBirney & Noyes 1979) and *in-situ* microrhythmic differentiation (Boudreau 1987), involving processes of crystal nucleation, resorption, coarsening, and chemical diffusion; and shifts in phase equilibria controlled by fluid exsolution due to the action of fluxing components (Rockhold *et al.* 1987). Such layering commonly occurs within mafic intrusions of low viscosity and high diffusivity, however, it is comparatively rare within felsic intrusions, particularly silica-oversaturated examples, where relatively low temperatures and high viscosities inhibit the development of layering (Emeleus 1963; Urbain *et al.* 1982; Rockhold *et al.* 1987).

One of the few examples of rhythmic layering in felsic intrusions within the Yilgarn Block, and the only example observed in a regional study of the felsic alkaline suite, occurs within the Eastern Goldfields Province of the Yilgarn Block at Gilgarna Rock, 103 km east-northeast of Kalgoorlie (Fig 1).

Geological setting

The syenites comprising Gilgarna Rock display mesoperthitic alkali feldspars, alkali pyroxenes and amphiboles, and low quartz contents typical of the felsic alkaline suite of Libby (1978).

A medium grained phase is intruded by a mineralogically and geochemically similar coarse grained phase, with recent Rb-Sr whole-rock and mineral dating (Johnson & Cooper 1989) establishing crystallization ages of 2627 ± 41 Ma and 2542 ± 14 Ma, respectively. The contact between the two phases is sharp, and sub-vertical rhythmic layering is observed within the younger coarse grained phase parallel

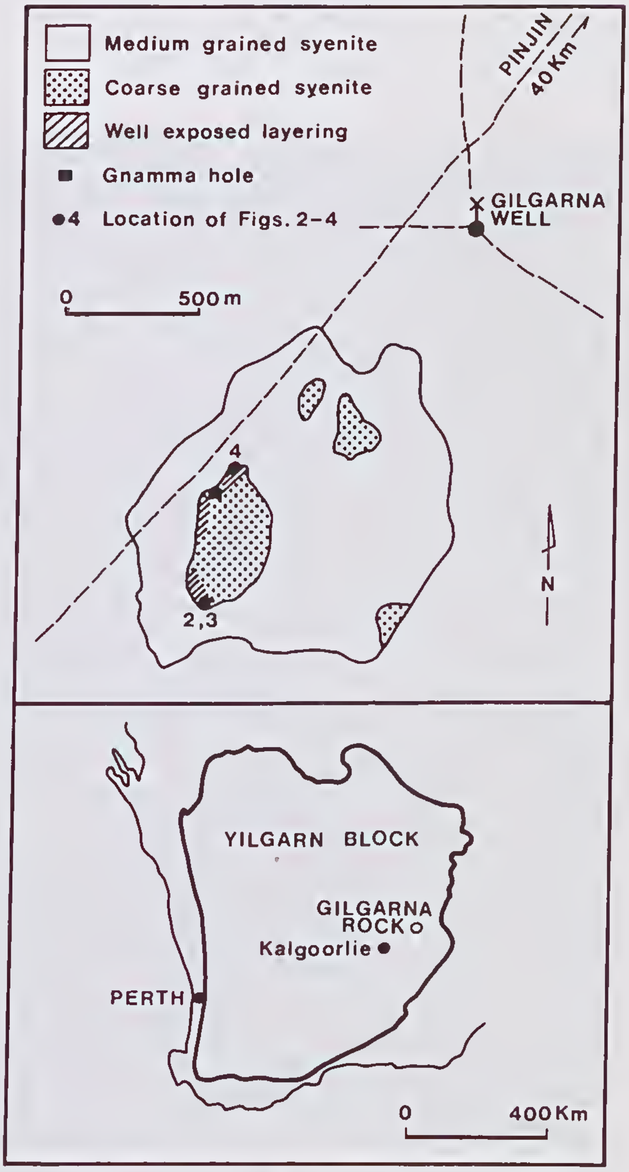

Figure 1 Location diagram and geological sketch, Gilgarna Rock.

to, and for distances of 1-5 m from, the contact. The layering is microrhythmic in form, often termed inch-scale layering (Hess 1960), and is defined by alternating predominantly mafic and predominantly felsic layers (Figs 2 & 3). Individual layers exhibit thicknesses of 0.5-15 cm, with minor pinching and swelling, and can be traced along strike for distances of up to 10 m.

Mafic layers are composed primarily of zoned alkali pyroxenes (>70%), with augite to aegirine-augite cores surrounded by aegirine-augite rims; feldspar (<20%), predominantly oligoclase to albite, with minor mesoperthite to antiperthite; titanite (5%); quartz (5%), usually as a late-stage interstitial phase; and accessory apatite and magnetite. Minor late alteration of alkali pyroxene to magnesioriebeckite is also present.

Felsic layers consist predominantly of feldspar (>80%), with medium to coarse grained oligoclase to albite and mesoperthite to antiperthite, and a mineralogically identical finer grained component with up to 10% quartz. Zoned augite/aegirine-augite (<20%) and trace titanite are the other constituents.

Elsewhere within the coarse phase syenite, oligoclase-albite occurs only as rare remnant cores to alkali feldspars. The common occurrence of oligoclase-albite in the felsic layers described above reflects early feldspar precipitation: with continued cooling, plagioclase moves down the solidus surface and is eventually replaced by anorthoclase as the crystallizing phase (Carmichael *et al.* 1974). Sub-solidus unmixing of anorthoclase leads to the development of mesoperthite to antiperthite.

Within both types of layers, occasional very thin layers of the other type occur, almost down to single-crystal scale in some cases. There is no indication of density grading within individual layers, and no relationship between layer spacing and crystal grainsize. Contacts between the rhythmic layers are generally sharp, although there are some rather diffuse examples. Sedimentary-type features within the layering are common, and include scour and fill structures, cross bedding, disrupted and slumped blocks, indistinct features approaching flame structures in form, and small-scale syn-crystallization microfaults (Fig 4). In addition, orbicular structures up to 0.75m long by 0.5m wide are present, with margins defined by concentrations of mafic minerals up to 30mm in thickness. All facing criteria suggest the influence of currents towards the contact of the medium grained phase, that is, away from the interior of the coarse grained phase.

Evidence of autometasomatism at Gilgarna Rock includes albite rimming of early mesoperthitic feldspars, aegirine-rich rimming of augite/aegirine-augite, partial replacement of pyroxene by magnesioriebeckite, and trace patchy colourless mica and fluorite replacement of feldspar. These autometasomatic products are best developed towards the margins of the coarse phase, and in the immediately adjacent medium phase.

Discussion

The lack of crystal sorting or density grading within individual layers at Gilgarna Rock argues against the major influence of crystal settling and convection processes on the

Figure 2 Microrhythmic (inch-scale) layering within the coarse phase syenite, Gilgarna Rock.

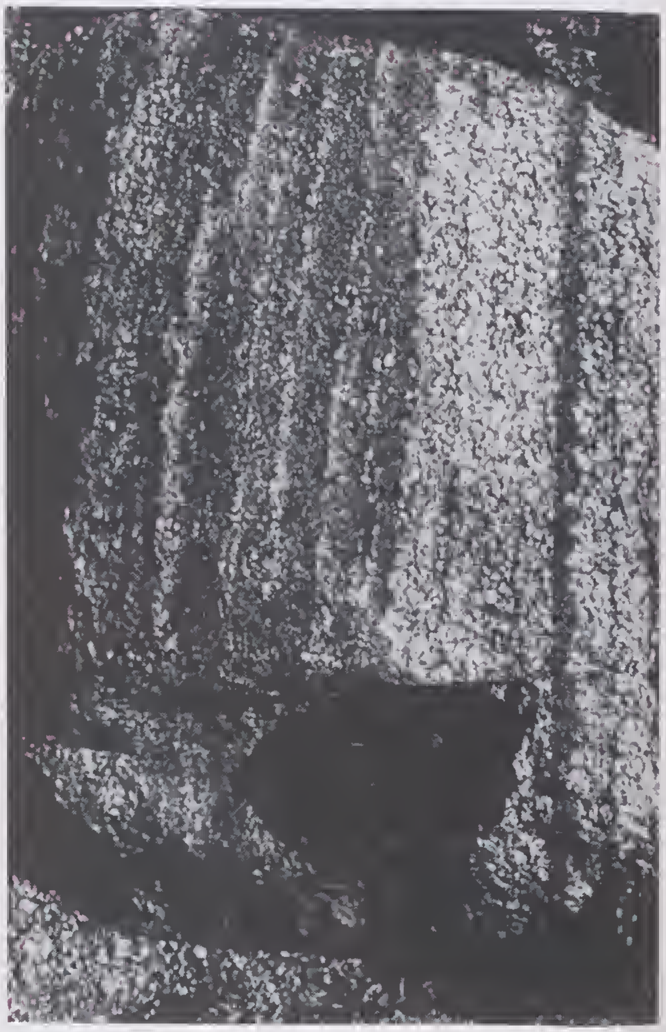

Figure 3 Alternating pyroxene-rich and feldspar-rich layers, Gilgarna Rock.

development of the microrhythmic layering. Similarly, lack of a relationship between layer spacing and crystal grain-size suggests that the processes of crystal nucleation, resorption and coarsening outlined by Boudreau (1987) are not significant at Gilgarna Rock. Notwithstanding the presence of minor disrupted blocks (Fig 4), the uniform and sharply defined layers at Gilgarna Rock are not consistent with the surge-type density currents and subsequent crystal mingling suggested as the major mechanism for undersaturated syenites of the Coldwell Complex, Ontario (Mitchell & Platt 1982).

The occurrence of these layering features within rocks derived from normally quite viscous magmas, leads to consideration of the processes capable of overcoming the limiting effects of high viscosity on the development of rhythmic layering. High viscosities in felsic melts result from a three-dimensional network of interconnected aluminate and silicate tetrahedra, where all oxygens form bridging bonds between pairs of tetrahedral cations (Dingwell & Myson 1985). The effects of fluxing components on such polymerized melts is to disrupt the network structure, depolymerize the melt, and thus enhance the diffusivity of components (Chorlton & Martin 1978; Pichavant 1981; Manning 1981).

In a study of similar layering to that of Gilgarna Rock within the Calamity Peak granite of South Dakota, Rockhold *et al.* (1987) concluded that the presence of fluxing components, such as boron or fluorine, can play a critical part in the development of rhythmic layering within granitic rocks. They suggested that depletion of boron in the melt, via tourmaline crystallization, decreased the solubility of H_2O in the melt, leading to the exsolution of an aqueous fluid. This was responsible for shifts in phase equilibria, with alternating mineral products as the crystallization front moved through the melt leading to the development of rhythmic layering.

Figure 4 Scour and fill structures within coarse phase syenite, Gilgarna Rock. Arrow indicates facing direction; zone 1 represents early layering subsequently modified by scours 2 and 3. Note disrupted blocks in zone 1, syncrystallization micro-faults within zones 2 and 3, and orbicular structure within late-stage relatively massive syenite, which truncates the base of zone 1.

Tourmaline does not occur in the Gilgarna Rock syenite, however, a thorough geochemical investigation of a suite of Gilgarna Rock samples indicates fluorine levels as high as 1900 ppm (author's unpublished data). Emeleus (1963) stressed the importance of fluorine in promoting rhythmic layering in the Gardar granites of Greenland. Manning (1981) showed that fluorine can have a more pronounced influence than boron in driving the crystallizing magma towards Ab in the Qz-Ab-Or system, and in decreasing the solidus temperature.

At Gilgarna Rock, fluorine depletion in the melt, by incorporation into pyroxene and eventually fluorite, could have lead to the exsolution of an aqueous fluid during crystallization. Such an increase in fluid pressure is capable of decreasing liquidus temperatures to such an extent, that pyroxene replaces feldspar as the primary phase at the liquidus (Parsons & Becker 1987). In a closed system, regular mineral layering may occur via an internally self-regulating rhythmic process (eg Maaloe 1987), but at Gilgarna Rock, irregular layer thicknesses suggest an irregular control. Periodic and repetitive changes in volatile pressure, causing shifts in the position of the eutectic of the crystallizing system, and hence rhythmic alternation of mineral layers, were proposed by Redden (1963) for some layered rocks from South Dakota, and by Parsons and Becker (1987) for the Klokken complex of South Greenland. At Gilgarna Rock, a similar model is proposed, with irregular stages of pressure release resulting in periodic increases in liquidus temperatures, causing feldspar precipitation. Subsequent build-up of fluid pressure due to further removal of fluorine from the melt could have returned the system to pyroxene precipitation, until the next stage of pressure release.

The confinement of the rhythmic layering to the margins of the coarse phase, and the stronger development of autometasomatic products in the medium phase adjacent to the contact zone, suggest that pressure release was facilitated via movement of the aqueous fluid into the medium phase in this zone. The sedimentary-type features, which indicate the localised presence of strong currents, display facing directions which are consistent with the progressive passage of fluids away from the interior of the coarse phase, towards the medium phase.

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